Transportation Research Part D 63 (2018) 333–346

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Natural variability in exposure to fine particles and their trace elements during typical workdays in an urban area

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ARTICLE INFO

Keywords:
Fine particulate matter
Personal exposure
Black carbon
Trace metals
Urban routes

ABSTRACT

Studies on the natural human exposures to fine particulate matter ($PM_{2.5}$) and their elements composition are practically non-existent in South America. In order to understand the natural exposure of the typical Brazilian population to $PM_{2.5}$ and their trace element composition, we measured $PM_{2.5}$ concentrations and collected mass on filters for nine continuous hours during a typical workday of volunteers. In addition, bus routes were performed at peak and non-peak periods, mimicking the routine activity of the population. Mean concentrations of $PM_{2.5}$ in the bus and car groups were similar while the fraction of BCe was higher for the bus group. For all routes, mean $PM_{2.5}$ concentrations were higher during peak than non-peak hours, with an average of $43.5 \pm 33.1\,\mu g\,m^{-3}$ and $14.3 \pm 10.2\,\mu g\,m^{-3}$, respectively. The trace elements S, K and Na originated mainly from vehicle emissions; Na was associated with the presence of biofuel in diesel. Toxic elements (Pb, Cr, Cu, Ni, Zn, Mn) were found at low levels as evident by the total hazard index that ranged from 2.15×10^{-03} to 1.38 for volunteers. For all routes, the hazard index ranged from 2.25×10^{-03} to 5.03. Average $PM_{2.5}$ respiratory deposition dose was estimated to be 0.60 µg/kg-hour for peak hours. Potential health damages to people during their movements and at workplaces close to the traffic were identified. Improvements in the design of the building to reduce the entrance of air pollutants as well as the use of filters in the buses could help to limit population exposure.

1. Introduction

Air pollution is one of the most pressing environmental issues in both developing and developed countries (Kanada et al., 2013; Chung et al., 2011; Fotourehchi, 2015). Annually around three million people die prematurely worldwide as a result of solely to ambient (outdoor) air pollution exposure, with more than half of them in developing countries (WHO, 2016).

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https://doi.org/10.1016/j.trd.2018.06.010

There is a lack of observational data across South America, especially in medium-sized cities. About one-third of the Brazilian population live in medium-sized urban areas (IBGE, 2017). These cities are involved in polluting activities similar to those in found megacities. Beal et al. (2017) performed an analysis of the inorganic chemical composition of fine particulate matter ($PM_{2.5}$) in two medium-sized cities. They found that the fraction of ions is very close to that observed in Asian cities and significantly higher compared with the other areas of Brazil, possibly due to the increased influence of biomass and waste burning Martins et al. (2018).

The origin and chemical composition of the particles are associated with negative health responses. Published research points out that particles from combustion, including those emitted by vehicular traffic, are particularly harmful (Laden et al., 2000; Peters, et al., 2004; Halonen et al., 2009; Mccreanor et al., 2007; Bos et al., 2011; Weichenthal et al., 2011; Anderson et al., 2012; WHO, 2016; Upadhyay et al., 2014; Gehring et al., 2015). Fine particles have higher loads of toxic metals in relation to coarse particles (i.e. $PM_{2.5\text{-}10}$). Consequently, these have a greater potential for health damage as they can penetrate more deeply into the lungs (Dockery et al., 1993; Cascio et al., 2009; Massey et al., 2013).

The impact of heavy diesel-powered vehicles (e.g., buses and trucks) on urban areas in Brazil is significant (Loyola et al., 2009). Although gasoline-powered vehicles are known to represent a major source of air pollutant emissions, diesel engines have been characterized by emissions of higher levels of PM (Hess et al., 2010). Diesel-powered vehicles in Brazil do not use filters since they follow the EURO 5 phase standards.

Even during a short exposure, urban transportation can contribute significantly to the total daily personal exposure, especially in relation to the BC (Rivas et al., 2016). Commuting is considered the time when people are most exposed to atmospheric pollutants during their daily activities, even in small cities (Kumar et al., 2017; De Almeida et al., 2018; Kumar et al., 2018a). The micro-environment of urban transport, for example, is not restricted only to people in the vehicles but includes those waiting for the bus at terminals and bus stops located close to heavy traffic or congested streets (Zhang and Batterman, 2013; Kaur et al., 2007).

The characteristics of indoor and outdoor environments are important to define population exposure to PM. Urban areas have different morphologies and people perform different work activities on a daily basis. As pointed by Fantke et al. (2017), an integrated coupled indoor-outdoor exposure assessment is still needed to compare $PM_{2.5}$-related intake fractions from a wide range of human activities. Thus, among other actions, it is fundamental to measure personal exposure to $PM_{2.5}$ in several different scenarios (urban areas, building types, workplaces, etc) around the world to support this integrated evaluation.

Past studies have made valuable contributions to existing literature (Rivas et al., 2016; Rivas et al., 2017) using fixed origin and destination points and measuring $PM_{2.5}$ and BC (Targino et al., 2016; Kumar et al., 2018b). This study assesses the natural movement of people during commuting in a typical city environment and their exposure to pollutants during a typical workday. Furthermore, the aim is to understand the relationship between concentrations in outdoor and indoor environments, the trace element composition on $PM_{2.5}$, and their potential health damage.

We performed measurements of personal exposure to $PM_{2.5}$ concentrations and their trace element composition during typical workdays on 30 volunteers. Given that buses are dominant means of public transportation in Brazilian cities, we measured personal exposure on numerous bus routes to better understand the natural exposition of the population.

2. Material and methods

2.1. Study area

The study was conducted in Londrina, a medium-sized Brazilian city with a population of about 550,000, of which about 97% live in the urban area. The main economic activities of this city are agribusiness, commerce and services. The vehicle fleet in this city includes 382,000 vehicles; of which 49% burn gasohol (25% anhydrous ethanol and 75% gasoline), 35.4% are flex-fuel, 6.8% burn diesel (8% of biodiesel is adding to diesel), and 8.8% others types (IBGE, 2017).

The climate is subtropical with precipitation distributed along the year, with hottest summers from December to March (average of medium temperature of 24 °C) and drier and cold winters from May to August (16 °C and 18 °C). Fig. 1 shows the urban area and the natural routes performed by volunteers that used the car (Fig. 1A) and buses (Fig. 1B) as a transportation mode.

2.2. Selection of volunteers, routes and sampling design

A convenience sample of 30 volunteers from the city of Londrina was selected to first have a view of the natural variability of the population exposure to fine particles during their displacements and work activities. The volunteers were adults from both genders and from different work activities, which accounted for the majority of the total active working class in the city. Volunteers from specific sectors (construction, agricultural, manufacturing, etc.) as well as individuals who smoked were not selected. All volunteers agreed to participate in the research, received a previous explanation, and signed the Free and Informed Consent Form (study approved by the Research Ethics Committee, under the number 30166214.9.0000.5547).

Samples were taken over each individual's typical workday, including commuting from home to work and time spent in the work environment. The prevalent transportation mode used by volunteers was cars (63%) and buses (30%). Table 1 shows the main characteristics of the routes performed by volunteers.

To better address the natural exposition of the population, five bus lines from the public transport system were selected based on the greatest demands and in order to cover all regions of the city. The bus is the main mode of public transportation used by a large part of the population of Londrina and other Brazilian cities.

The lines were named according to the direction of their route; from the central region of the city to the East (Route 1) with